

NUCLEUS-NUCLEUS COLLISIONS AT LOW ENERGIES. THE EFFECTS FROM NON VACUUM EXCHANGE

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Abstract

Experimental data on total and differential elastic cross sections for $p + p(\bar{p})$, $n + p(\bar{p})$, $K^\pm + p$, $K^\pm + n$, $\pi^\pm + p$ starting from energy 3.5 GeV in CMS are used to determine parameters of vacuum contribution and parameters of basic non vacuum reggeons: f , ω , ρ and A_2 . It is argued that non vacuum contributions to proton-proton and proton-neutron collisions correspond to spectrum in which baryon number is moved from the fragmentation region to central region in rapidity space. In this case it is possible that chemical potential is increased in central region of spectrum of nucleus-nucleus interaction at low energies. This effect might be important for facilities FAIR and NICA.

1 Introduction

Processes with multiple production at high energies are intensively studied both experimentally and theoretically. At that time behavior of multiple processes at low energies $\sqrt{s} \approx 3.5 \div 10$ GeV is known much less. Multiple processes at low energies are dominated by contributions of non vacuum reggeons. While “pomeron physics” is considerably well explored basing on QCD ([1] – [6], also see [7] and references therein) clear QCD based picture of multiple processes, associated with non vacuum reggeons is still missing.

At low energies ($\sqrt{s} = 3.5 \div 10$ GeV in center-of-mass system) non vacuum exchange can give up to half of total cross sections value in pp and pn interactions. So its analysis is important for better understanding of nucleus-nucleus scattering processes, which will occur at facilities FAIR and NICA. Unlike works [8], [9] we consider four basic non vacuum reggeons. The extensive data set of the Particle Data Group [10] at low energies gives possibility to do it. Firstly this approach is more correct. Secondly knowledge of quantum non vacuum exchange numbers can be essential for signatures of different processes which take place when passing of nucleus through nucleus.

In present work we will study out which “color diagrams” correspond to non vacuum reggeons. Analysis of these color diagrams will show that at low energies baryon number increase in central region of produced particles spectrum. For nucleus-nucleus collisions it means that baryon chemical potential is increased

in central region of spectrum. This may lead to discovery of phase transition to quark-gluon plasma at energies of facilities NICA and FAIR.

2 Total cross sections of various reactions

In the Low Constituents Number Model (LCNM) [5], [6] total cross sections can be presented as sum of two parts – vacuum contribution rising as logarithm of full energy squared and non vacuum contribution. Vacuum contribution contains constant part and terms proportional to logarithm of full energy and to logarithm of full energy squared. These terms correspond to contributions of one and two additional gluons in initial state.

We consider exchange of four basic non vacuum reggeons: f -, ρ , ω and A_2 -mesons. Therefore formulas for total cross sections can be written as follows.

$$\begin{aligned}
\sigma_{tot}^{pp(\bar{p})} &= \sigma_0^{pp} + \sigma_1^{pp} \ln s + \sigma_2^{pp} \ln^2 s + \\
&\quad g_f^p g_f^p s^{-\Delta_f} \pm g_\rho^p g_\rho^p s^{-\Delta_R} \pm g_\omega^p g_\omega^p s^{-\Delta_R} + g_{A_2}^p g_{A_2}^p s^{-\Delta_R} \\
\sigma_{tot}^{np(\bar{p})} &= \sigma_0^{np} + \sigma_1^{np} \ln s + \sigma_2^{np} \ln^2 s + \\
&\quad g_f^p g_f^p s^{-\Delta_f} \pm g_\rho^p g_\rho^p s^{-\Delta_R} \mp g_\omega^p g_\omega^p s^{-\Delta_R} - g_{A_2}^p g_{A_2}^p s^{-\Delta_R} \\
\sigma_{tot}^{K^\pm p} &= \sigma_0^{Kp} (1 + \delta_1^{pp} \ln s + \delta_2^{Kp} \ln^2 s) + \\
&\quad g_f^K g_f^p s^{-\Delta_f} \mp g_\rho^K g_\rho^p s^{-\Delta_R} \mp g_\omega^K g_\omega^p s^{-\Delta_R} + g_{A_2}^K g_{A_2}^p s^{-\Delta_R} \quad (1) \\
\sigma_{tot}^{K^\pm n} &= \sigma_0^{Kn} (1 + \delta_1^{pp} \ln s + \delta_2^{Kp} \ln^2 s) + \\
&\quad g_f^K g_f^p s^{-\Delta_f} \pm g_\rho^K g_\rho^p s^{-\Delta_R} \mp g_\omega^K g_\omega^p s^{-\Delta_R} - g_{A_2}^K g_{A_2}^p s^{-\Delta_R} \\
\sigma_{tot}^{\pi^\pm p} &= \sigma_0^{\pi p} (1 + \delta_1^{pp} \ln s + \delta_2^{\pi p} \ln^2 s) + \\
&\quad g_f^\pi g_f^p s^{-\Delta_f} \mp g_\rho^\pi g_\rho^p s^{-\Delta_R}
\end{aligned}$$

The numerical values of all parameters are presented in Tables 1 and 2. The examples of fitting are shown for $np(\bar{p})$ in Figure 1. Experimental data were taken from the Particle Data Group [10].

Table 1: Values of vacuum parameters

σ_0 , mb	σ_1 , mb	σ_2 , mb	$\delta_1 = \sigma_1/\sigma_0$	$\delta_2 = \sigma_2/\sigma_0$
$pp, p\bar{p}, np, n\bar{p}$				
21.63 ± 1.94	0.84 ± 0.39	0.18 ± 0.02	0.04 ± 0.02	0.008 ± 0.001
$K^\pm p, K^\pm n$				
10.43 ± 0.88	0.40 ± 0.19	0.15 ± 0.02	0.04 ± 0.02	0.014 ± 0.002
$\pi^\pm p$				
11.52 ± 0.93	0.45 ± 0.21	0.17 ± 0.02	0.04 ± 0.02	0.015 ± 0.001

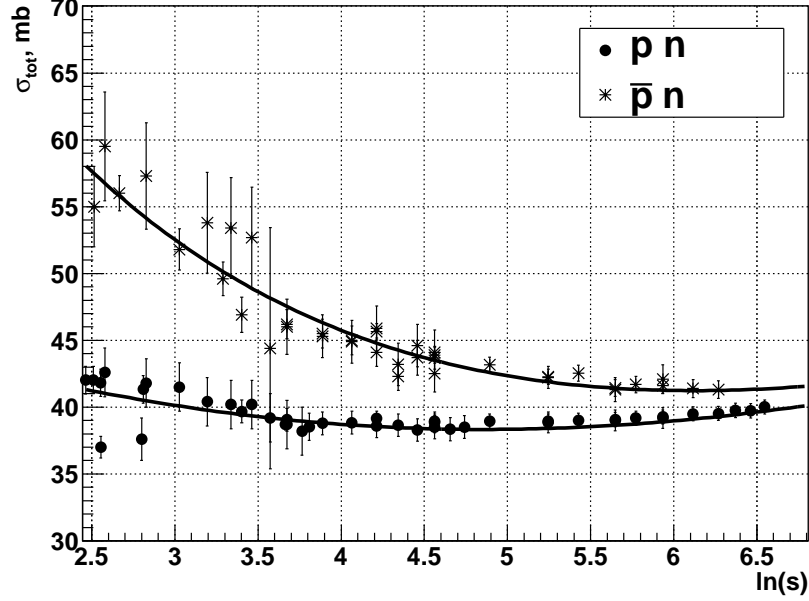


Figure 1: Fitting of total cross sections

Table 2: Values of non vacuum parameters

vertex	g^p , $\text{mb}^{1/2}$ (p, n, \bar{p})	g^K , $\text{mb}^{1/2}$ (K^\pm)	g^π , $\text{mb}^{1/2}$ (π^\pm)
f -meson	7.85 ± 0.20	2.46 ± 0.15	4.28 ± 0.11
ρ -meson	1.51 ± 0.21	2.05 ± 0.35	3.75 ± 0.35
ω -meson	6.00 ± 0.14	1.88 ± 0.06	
A_2 -meson	1.33 ± 0.24	1.64 ± 0.38	

3 Dual topological diagrams

Hadrons interactions with exchange of non vacuum reggeon correspond to soft processes with flavor transfer in t channel. Since only slow partons softly interact with each other, initial state configurations where one of valence quarks has low momentum are very essential.

In frame of dual resonance model ([11] – [14]) slowing of quark and reggeon exchange is depicted as dual diagram in Fig. 2a (we consider $\pi^+\pi^-$ scattering).

In this approach hadrons (mesons) represent string with quark and antiquark at its endpoints. When moving in 4-dimensional space-time string sweeps out 2-dimensional surface. Diagram in Fig. 2a shows elastic interaction. String endpoints of initial state merge and further one quark string moves in s channel, which then splits into two strings. Consequently elastic scattering amplitude ap-

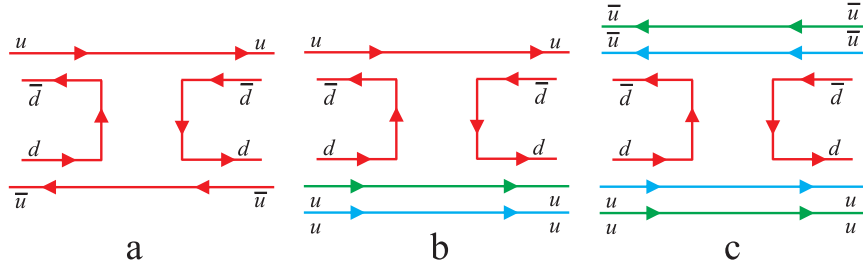


Figure 2: a) Dual diagram for $\pi^+\pi^-$ scattering. b) Dual diagrams for π^+p interaction. Completely analogous diagram can be drawn for π^-p scattering. c) Dual diagram for $p\bar{p}$ scattering.

pears, which constitutes smooth 2-dimensional surface. The same 2-dimensional surfaces correspond to amplitudes of n particles production. More complicated structure, in which hollow cylinder is glued to poles that are swept out by strings of initial hadrons, corresponds to pomeron.

Dual resonance model gives independent inference of reggeon diagram technique, which does not use expansion in colorless particles of amplitudes or parton wave functions. The AGK theorem [15] may be obtained also in frame of this approach [7]. Dual diagrams for $\pi^\pm p$ and $p\bar{p}$ interactions are given in Fig. 2b and 2c.

In case of $\pi^\pm p$ interaction there is stage when only quark string moves in s channel, similarly to diagram in Fig. 2a. Endpoints of this string are quark and diquark.

In case of $p\bar{p}$ interaction region is swept out by string with quark and diquark at its endpoints.

In what follows we will construct color diagrams for non vacuum reggeons using two results, obtained from consideration of dual diagrams DRM.

1. In s channel of color diagrams there must exist quark string, which is not divided into several parts. This string has quarks (antiquarks) and diquarks (antidiquarks) at its endpoints.

2. In t channel elastic amplitudes, describing reggeon contributions, must have quark-antiquark pair.

4 Color diagrams for nucleon-nucleon scattering

There are no dual diagrams for nucleon-nucleon collisions (we will consider proton-proton scattering as example). This process is described by so-called twist diagrams, in which scattering of slowed quarks takes place, but not annihilation of quark and antiquark. In the first approximation of DRM such diagrams do not contribute to imaginary part of nucleon-nucleon scattering. So non vacuum Regge contributions which are present in meson-nucleon and antinucleon-nucleon interactions must not exist in case of nucleon-nucleon in-

interactions. But these contributions are visible in experimental data and parameters of their Regge trajectories (intercepts and slopes) coincide with Regge trajectories parameters of $\pi^\pm p$, $K^\pm p$, $p\bar{p}$, $n\bar{p}$ collisions.

Therefore there must exist a diagram which fulfills requirements of dual diagrams. We have found two diagrams of process with one quark string in s channel, Fig. 3.

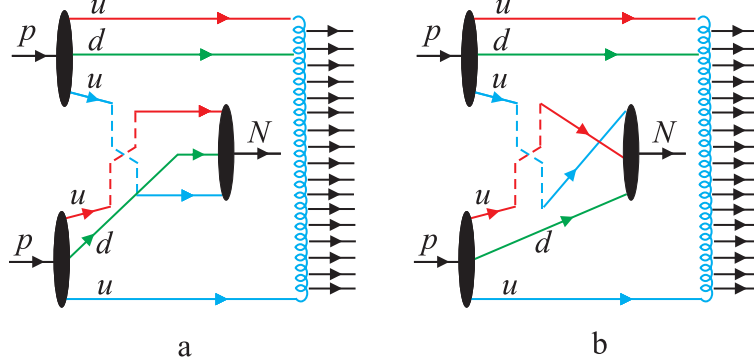


Figure 3: pp interaction.

In diagram from Fig. 3a quarks move forward after scattering, in diagram from Fig. 3b they move backward. In order to form one quark string in s channel one of protons must be taken in configuration with slowed diquark. String in s channel has quark and diquark at its endpoints. Since this string breaks out into secondary hadrons, then slow state with three quarks also forms colorless state – some baryonic resonance.

5 Conclusions

Thus we can argue that leading non vacuum reggeons in nucleon-nucleon scattering (proton-proton, proton-neutron and neutron-neutron) result in translocating of baryons from fragmentation region to central region of secondary hadrons spectrum.

The obtained result means that in nucleus-nucleus scattering at low and intermediate energies baryon number may increase in central region of secondary hadrons spectrum. This may help in discovering quark-gluon plasma effects in facilities NICA and FAIR.

We have come to conclusions by studying structure of color diagrams for non vacuum reggeons. Evidently, further detailed analysis is necessary. Though many important results were obtained only from structure of diagrams in $\lambda\varphi^3$ theory. In particular, the first proof of the AGK theorem was derived exactly from analysis of ladder diagram structure in $\lambda\varphi^3$.

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References

- [1] E.A. Kuraev, L.N. Lipatov and V.S. Fadin, Sov. Phys. JETP **44** (1976) 443.
- [2] I.I. Balitsky, L.N. Lipatov, Sov. J. Nucl. Phys. **28** (1978) 822.
- [3] V.A. Abramovsky, O.V. Kancheli, Pisma Zh. Eksp. Teor. Fiz. **31** (1980) 566.
- [4] V.A. Abramovsky, O.V. Kancheli, Pisma Zh. Eksp. Teor. Fiz. **32** (1980) 498.
- [5] V.A. Abramovsky, N.V. Radchenko, Particles and Nuclei, Letters **6** (2009) 607.
- [6] V.A. Abramovsky, N.V. Radchenko, Particles and Nuclei, Letters **6** (2009) 717.
- [7] V.A. Abramovsky, E.V. Gedalin, E.G. Gurvich, O.V. Kancheli, Inelastic interaction at high energies and chromodynamics, Tbilisi, Metzniereba, 1986 (in russian).
- [8] A. Donnachie, P.V. Landshoff, Phys. Lett. **B 296** (1992) 227.
- [9] J.R. Cudell et al., Phys. Rev. **D 61** (2000) 034019.
- [10] C. Amsler et al., Review of Particle Physics, Phys. Lett. **B 667** (2008) 1.
- [11] C. Rebbi, Phys. Rept. **C12** (1974) 2.
- [12] S. Mandelstam, Phys. Rept. **C13** (1974) 259.
- [13] J. Scherk, Rev. Mod. Phys. **47** (1975) 123.
- [14] G.F. Chew, C. Rosenzweig, Phys. Rept. **41** (1978) 263.
- [15] V.A. Abramovsky, V.N. Gribov, O.V. Kancheli, Sov. J. Nucl. Phys. **18** (1974) 308.